AVIRIS LAND-SURFACE MAPPING IN SUPPORT OF THE BOREAL ECOSYSTEM-ATMOSPHERE STUDY (BOREAS)

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1 Introduction

A key scientific objective of the original BOREAS field campaign (1993-1996) was to obtain the baseline data required for modeling and predicting fluxes of energy, mass and trace gases in the boreal forest biome. These data sets are necessary to determine the sensitivity of the boreal forest biome to potential climatic changes and potential biophysical feedbacks on climate (Sellers et al., 1997). A considerable volume of remotely-sensed and supporting field data were acquired by numerous researchers to meet this objective. By design, remote sensing and modeling were considered critical components for scaling efforts, extending point measurements from flux towers and field sites over larger spatial and longer temporal scales. A major focus of the BOREAS follow-on program is concerned with integrating the diverse remotely sensed and ground-based data sets to address specific questions such as carbon dynamics at local to regional scales. The Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) has the potential of contributing to BOREAS through: 1) accurate retrieved apparent surface reflectance; 2) improved land-cover classification and 3) direct assessment of biochemical/biophysical information such as canopy liquid water and chlorophyll concentration through pigment fits. In this paper, we present initial products for major flux tower sites including: 1) surface reflectance of dominant cover types; 2) a land-cover classification developed using spectral mixture analysis (SMA) and Multiple Endmember Spectral Mixture Analysis (MESMA), and 3) liquid water maps. Our goal is to compare these land-cover maps to existing maps and to incorporate AVIRIS image products into models of photosynthetic flux.

2 Background

A large number of techniques have been developed that utilize the spectral contrast between leaves and background materials (e.g. soils) and the manner in which this contrast changes at canopy scales (due to increasing leaf area, etc.) to derive biophysical parameters used in models. Critical model parameters include leaf area index (LAI), and absorbed photosynthetically active radiation (APAR). These input parameters are typically estimated using ratio-based techniques, such as the Normalized Difference Vegetation Index (e.g. Tucker 1979; Tucker et al. 1983; Asrar et al. 1989; Sellers 1985). Through time series and image compositing, NDVI provides an additional temporal measure of how these parameters change, providing a means to monitor fluxes and productivity (e.g Tucker et al., 1983). NDVI, while highly successful for agriculture and grassland ecosystems has been found to be less successful in forested ecosystems (Hall et al., 1995). Furthermore, ratio-based indices have been shown to be subject to variation associated with changes in atmospheric turbidity, soil background reflectance and solar illumination (Elvidge and Lyon, 1985; Huete, 1989; Deering et al., 1994).

Linear spectral mixture analysis (SMA) offers an alternative approach to current techniques based on the NDVI. SMA is based on the assumption that the spectrum measured by a sensor is a linear or non-linear combination of the spectra of components within the instantaneous field of view (IFOV). If photons predominantly interact with a single component, the mixed spectrum can be modeled as the sum of the pure spectra (endmembers) within the IFOV, weighted by the areal proportion of each material. If photons interact with multiple components, nonlinear spectral mixing can become significant (Roberts et al., 1993). For most remote sensing applications, a linear mixing model has been assumed (Graetz and Gentle, (1982) Smith et al., (1990); Roberts et al., (1993); Shimabukuro et al., (1994)), although non-linear mixing can be important in vegetation where significant multiple scattering occurs (Roberts et al., 1993; Borel and Gerstl, 1994). Vegetation structure is expressed as variation in either spectral fractions, or one of the other linear measures. For example, a forested ecosystem might be best modeled as a mixture of green leaves, shadows and exposed branches or litter (Nonphotosynthetic Vegetation: NPV). Early regeneration of conifers might be distinguished from old growth forest by a decrease in green leaves, an increase in canopy shadows (gaps) and increase in wood as exposed branches and snags (Heilman et al., 1996). Recently, Hall et al., (1995) combined linear spectral mixture analysis with geometrical optical models in Boreal forests and found this approach to provide improved estimates of canopy biophysical properties than the NDVI.

An alternative approach towards direct estimation of a biophysical parameter is indirect estimation through classification. This approach is viable where biophysical properties vary markedly from one type of land cover to another. Furthermore, it is commonly necessary as a means to account for physiological differences between major vegetation types, required for predicting carbon uptake, photosynthesis, transpiration or other important drivers as they may vary between vegetation types.

Currently, most biogeochemical/hydrological models are driven off biophysical parameters estimated using the NDVI. For example, LAI and APAR estimated from NDVI are used as input parameters in to models such as CASA, SIB2 and ForestBGC (Nemani and Running, 1989; Potter et al. 1993; Sellers et al. 1996). While this approach may work in a large number of non-forested ecosystems, NDVI has limitations in forested ecosystems, especially for LAI (e.g. Hall et al., 1995). Furthermore, this approach does not take advantage of additional parameters that could be derived from alternate approaches such as SMA. For example, in addition to the green vegetation (GV) fraction, which has been shown to be highly correlated with NDVI (Roberts et al., 1997a), SMA provides other relevant estimates of canopy structure, including subpixel shading (shade fraction) and NPV. Through time series and the use of reference endmembers, SMA can provide an alternate framework for estimating these biophysical parameters and monitoring changes through time.

In addition to known limitations in the NDVI in boreal ecosystems, a two-channel index fails to fully utilize the potential of spectrally rich data sets, such as CASI or AVIRIS. Imaging spectrometry is of value because it provides a contiguous spectrum across a range in wavelengths, thereby better quantifying atmospheric and surface properties in terms of their direct chemical and physical attributes (Vane et al., 1993). As a result, the atmosphere can be characterized and compensated to retrieve surface reflectance. With a large number of bands it becomes possible to identify and estimate chemical properties of plants such as liquid water thickness (Gao and Goetz, 1990, 1995; Green et al., 1991; Roberts et al. 1997a; Ustin et al., 1998), nitrogen, lignin and cellulose (Wessman et al., 1988; Curran, 1989;Gao and Goetz, 1995; Martin and Aber, 1997). Because plant chemistry and architecture vary between major vegetation types, genera and some species, the wealth of spectral information can be further used to better classify vegetation based on the subtle spectral differences apparent only in imaging spectrometer data. For example, Roberts et al., (1998a) developed a new technique, called MESMA to map chaparral to generic and species levels at a high accuracy (Gardner, 1997). When combined with a regionally specific library (Roberts et al., 1997b), this technique provides a means for determining apriori which species can be distinguished, then mapping them based on spectra relevant to the region of study. Multiple endmember concepts have also been extended to the problem of mapping snow covered area and snow grain size with image endmembers (Painter et al., 1998) and snow spectra synthesized using radiative transfer (Painter et al., 1997). Here we report on development of alternate products for BOREAS land-cover mapping developed from AVIRIS.

3 Methods

3.1 Data

A primary focus has been on acquiring radiometrically calibrated AVIRIS data from the Jet Propulsion Laboratory (JPL) and processing them to retrieve surface reflectance. Over 1000 AVIRIS scenes were acquired for BOREAS between 1994 and 1996. To date a total of 865 AVIRIS scenes have been acquired from JPL. Scenes were prioritized starting with calibration targets as the highest priority (SSA-Cal-W for 940419, 940721 and 940916) followed by a selection of scenes chosen by John Gamon (Table 1).

Table 1.0 Prioritized AVIRIS processing. Completed scenes are highlighted in bold.

Date	Scene	Status
940419Br2	**SSA-Cal-W**	**3 scenes, completed**
940721Br2	**SSA-Cal-W**	**3 scenes, completed**
940916Br2	**SSA-Cal-W**	**3 scenes, completed**
940419Br7	**SSA-East-J**	**8 scenes, completed**
940721Br7	**SSA-East-J**	**7 scenes, completed**
940916Br8	**SSA-East-J**	**7 scenes, completed**
940419Br3	**SSA-West-B**	**11 scenes, completed**
940721Br11	**SSA-West-B**	**10 scenes, completed**
940916Br11	**SSA-West-B**	**9 scenes, completed**
940420Br6	NSA-O	4 scenes, acquired
940804Br8	NSA-O	3 scenes, acquired
940917Br9	NSA-O	4 scenes, acquired
940721Br10	SSA-ThawX	6 scenes, acquired
940419Br12	**SSA-East-G**	**8 scenes, completed**
940721Br4	**SSA-East-G**	**8 scenes, completed**
940916Br5	**SSA-East-G**	**7 scenes, completed**
	Others	
940419Br4	**SSA-West-Thaw**	**6 scenes, completed**
940608Br2	**NSA-Thaw-X**	**8 scenes, completed**
940721Br3	**SSA-Thaw-Y**	**7 scenes, completed**
940916Br4	**SSA-East-I**	**7 scenes, completed**

3.2 AVIRIS Processing

AVIRIS data were processed to apparent surface reflectance using the approach described by Green et al. (1991). The general strategy has been to use ground spectral reflectance measurements acquired by Robert Green over a target in SSA-Cal-W to improved reflectance retrievals, then port the correction to all other scenes acquired within the same campaign. At times when no ground reflectance data exist, temporally invariant targets were used as a means of correcting data. Once reflectance was retrieved, two alternative approaches were used to map vegetation in the Boreal Forest. The first approach used simple SMA to generate fraction images of GV, soils, NPV and shade (Adams et al., 1993; Roberts et al. 1993). Our initial focus has been on the use of image endmembers (spectra derived from the image), but our long term objective is to develop a reference endmember library for the region. MESMA (Roberts et al., 1998a), was used to map vegetation dominants using image endmembers derived from known targets in the images. Canopy structure was assessed through analysis of spectral fractions derived from SMA and using equivalent liquid water as a potential measure of canopy structure (LAI; Roberts et al., 1998b). An overview of the analysis steps is shown in Figure 1.

4 Results

High quality apparent surface reflectance was retrieved at SSA-Cal-West (Figure 2). Correction factors developed from the calibration targets for July and September 1994 data sets were successfully exported to the April data assuming that the ground calibration site was temporally invariant. Assessment of the reflectance for winter (April scenes), suggests that this assumption was valid. Once a correction factor was established for each flight season, it was ported to other flight lines acquired on the same date. Analysis of multitemporal reflectance, derived for SSA-East J demonstrated the feasibility of extending the use of ground data beyond the calibration scenes (Figure 3). The spectra shown in Figure 3 represent some of the first high quality, canopy level spectra derived for BOREAS. In general, Boreal forest spectra can be characterized as having very low reflectance, with a maximum reflectance of 35% in the NIR for fens and quaking aspen (*Populus tremuloides*) and significantly lower reflectance in Jack Pine (*Pinus banksiana*) (< 20%) and Black Spruce (*Picea mariana*) (< 10%). Significant seasonal changes were observed in Fen, which reached peak greenness in July but was senescing by September and aspen, which retained leaves through September. The most seasonally stable vegetation in SSA-East-J was Jack Pine.

Vegetation dominants were mapped using MESMA and an initial set of image endmembers derived from identified ground targets (Figure 4). While preliminary and lacking any form of accuracy assessment, the initial results demonstrate an ability to map a majority of the land-cover types in the area using a series of two endmember models (a bright endmember + shade) based off of image endmembers. Preliminary results suggest black spruce was undermapped, potentially at the expense of bogs and muskeg.

5 Summary

Preliminary results for AVIRIS analysis at the BOREAS sites were encouraging. High quality reflectance has been retrieved for all calibration sites, for all dates. Furthermore, we found that the correction factors used to improve apparent reflectance retrievals at calibration sites could be ported to flight lines acquired on the same date but in different geographic areas. We are currently investigating the potential for locating temporally invariant targets. These targets will be needed for extending the reflectance retrievals to include flight lines acquired on dates where no calibration data were acquired.

Equivalent liquid water maps are generated as a byproduct of reflectance retrieval. Prior analysis of AVIRIS data acquired over clonal *Populus* suggests that liquid water may form an alternate measure of LAI. Initial comparisons in this study showed significant differences between NDVI and liquid water maps, suggesting that they are mapping different aspects of canopy structure or chemistry. SMA was applied using image endmembers to map GV, NPV, soil and shade. A near term objective of this study is to improve the analysis using a reference endmember library developed for BOREAS. MESMA results were very promising, demonstrating the ability to map vegetation cover in the area, but are preliminary.

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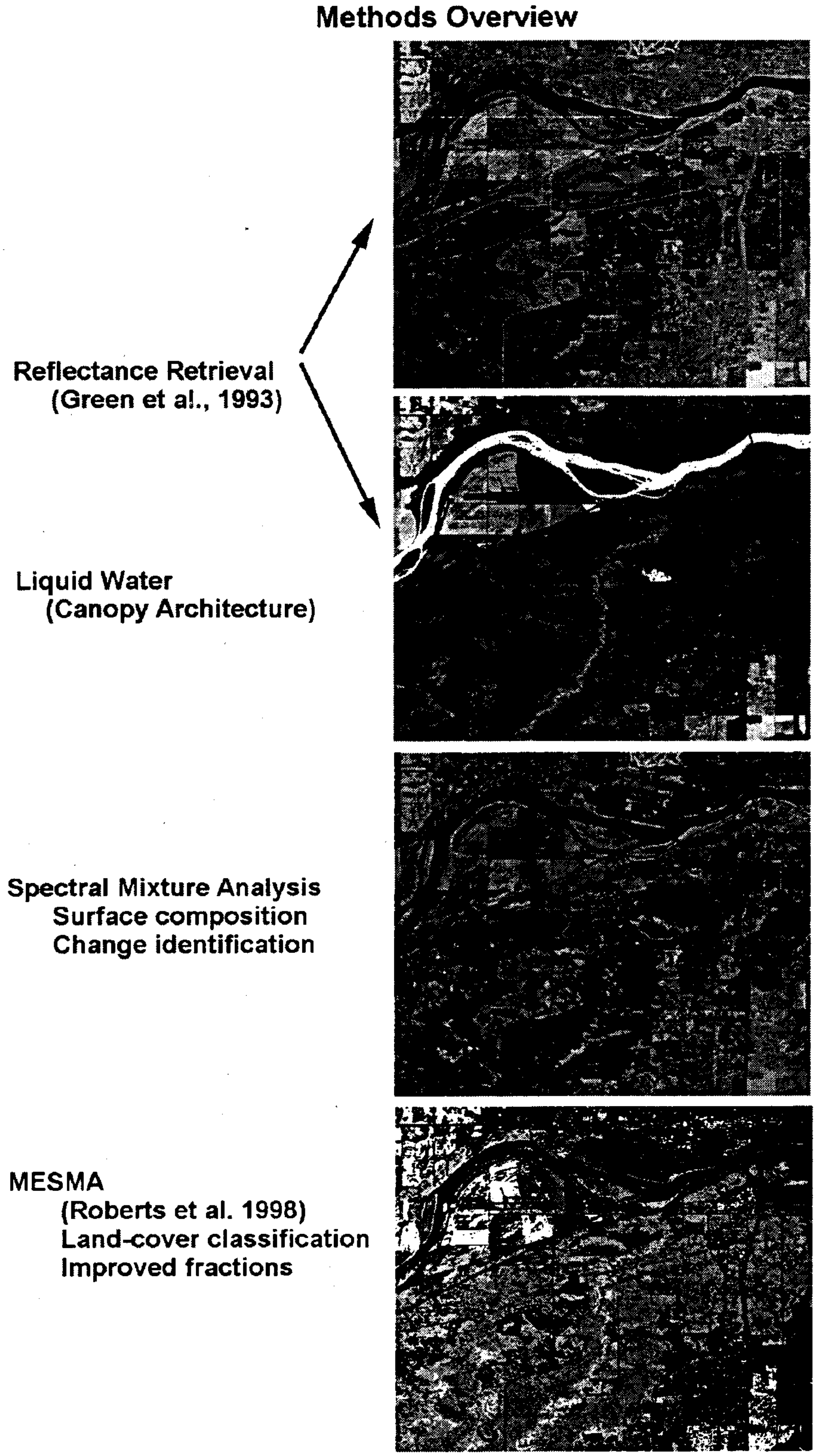


Figure 1) Techniques overview

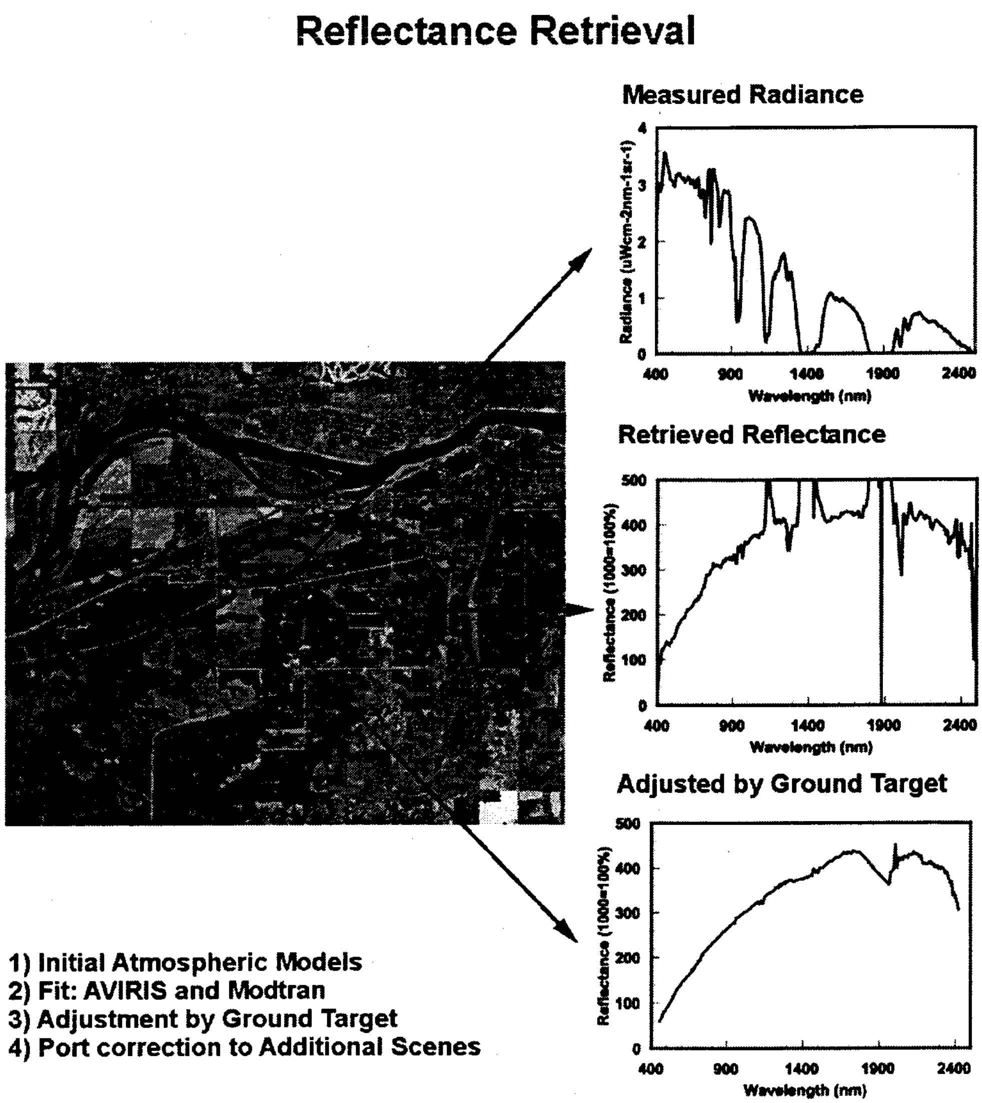
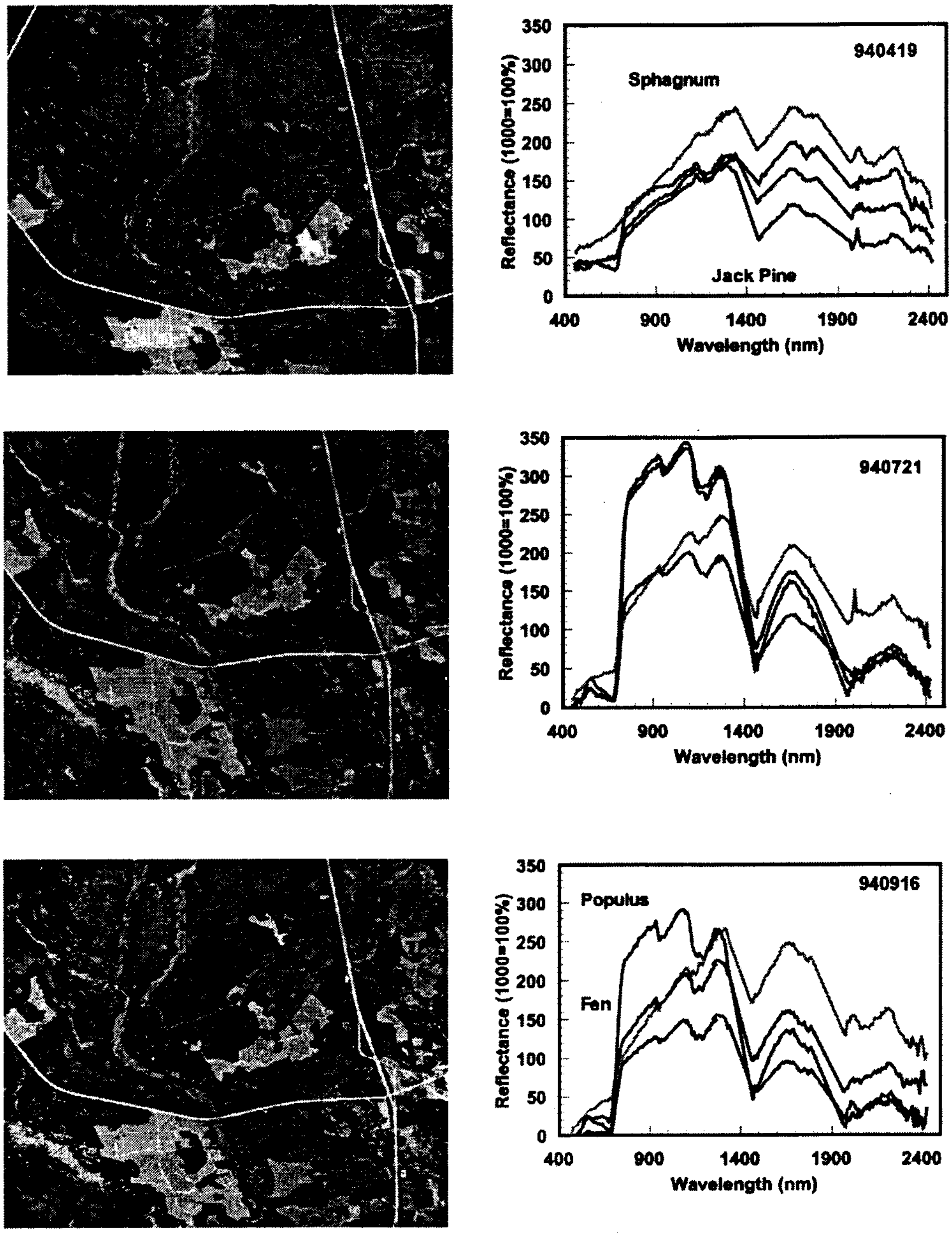


Figure 2) Reflectance retrieval at SSA-Cal-West

Transect J: Temporal Changes in Spectra



665, 836, 1603 nm: RGB

Figure 3) Multitemporal reflectance over select cover types in the Boreal forest.

Transect J: MESMA Land-cover Map

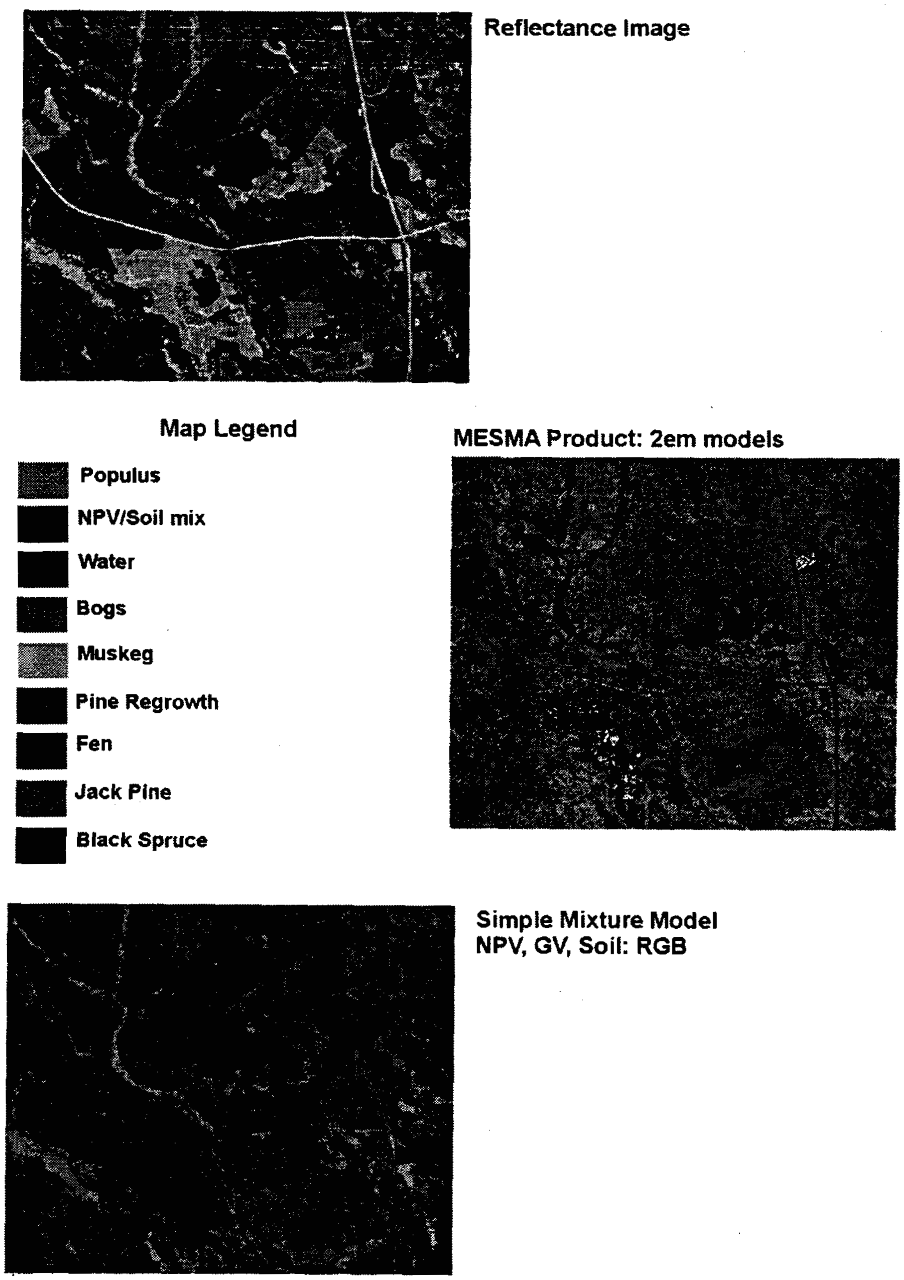


Figure 4) Initial MESMA map generated using image spectra.